Olympic Coast
National Marine Sanctuary

Side Scan Sonar Survey
Global Marine/Pacific Crossing

Cruise Report
OCNMS-HMPR-105-2001-01

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1 INTRODUCTION

The two PC-1 cables, North and East, were installed in a section of the Olympic Coast national marine sanctuary (OCNMS) in December 1999 and February 2000, respectively. Pacific Crossing (PC) contracted TYCOM to conduct the cable installation. Each cable transits approximately 30 nm of OCNMS. The geo-technical analysis from the pre-lay surveys was conducted by TYCOM, while C&C Technologies later suggested that the cable could be buried throughout the OCNMS. The post-lay reports did not indicate a burial depth except at a few discrete work sites, where burial ranged from 0 to 100 cm, with an average of approximately 25 cm. The intent of Global Crossing (GC) was cable burial between 60-100 cm below the grade of the surface sediments. In September of 2000, OCNMS personnel conducted a monitoring cruise to collect videography and sediment samples along the cable route in varied sediment types and in areas of varying fishing intensity as part of the OCNMS monitoring program. Only a portion of the east segment of the PC-1 project was observed, and a significant portion of that area was observed to be exposed. Exposure ranged from suspensions, to being surface laid on top of a plow scar, surface laid to the side of the plow scar, and suspensions within a jetted trench.

The purpose of this cable assessment survey, from the OCNMS perspective, was to obtain a complete assessment of the degree of burial success in the various sediment types and assess the current condition of the cable and scours in varying fishing intensity areas along the cable route. The results of this survey would enable PC to address the reasons for the depth of burial achieved, and also provide information for OCNMS to evaluate the impact to the benthic environment. It was also expected that this information would allow PC and OCNMS to assess the possible need for remediation activity.

The assessment survey was designed by GC to entail two cruises. The first of which was a geophysical cruise that entailed the use of Seafloor Survey International's SYS100D, which collected sonar imagery, bathymetry and sub-bottom profiling data. The second portion was a video survey of the cable route using a Global Marine (GM) ROV and a contract vessel. This field report addresses only the geophysical portion of the effort.

1.1 AREA SURVEYED

An area along the extreme northern boundary of the Sanctuary, bounded by coordinates 48N 22'36",125W 20'35", 48N 25'11" 124W 38'17", was surveyed from May 16 - May 18, 2001.

2 DATA ACQUISITION

2.1 VESSEL

The 210' research vessel Moana Wave was used as the primary survey platform (Figure 1).

Figure 1. R/V Moana Wave.

2.2 POSITIONING

The navigation system used was the FUGRO product, Starfix, which is a differential global positioning system that uses an array of base stations situated around the world. In this case, stations at Everett, Redding, and San Diego were used. Corrections to the NavSat ranges are transmitted through IMMARSAT satellites to the vessel. A position for the vessel is computed without correctors, and one with correctors from each of the base stations. A least squares adjustment is then made using the four solutions to calculate a final positioning.

2.2.1 Project Datum

Positional information supplied by DGPS was in the WGS84 datum (Table 1) and all online survey was conducted using this datum. Data sets were projected to the Mercator projection (Table 2) for mapping and display.

Table 1. Datum Parameters

Datum	WGS84
Spheroid	WGS84
Semi-major axis	6378137.000
Semi-minor axis	6356752.314
Inverse flattening (1/f)	298.2572236
Eccentricity squared (e^2)	0.006694380

Table 2. Projection Parameters

Projection	Mercator
Standard Parallel	32 N
Longitude of Origin	130 E
False Easting	0
False Northing	0

2.3 SIDE SCAN SONAR AND DATA LOGGING

The SYS100D is a dual head side scan sonar system (Figure 2). The operational range is from approximately 50 meters to 2000 meters. Ping rate was set at 2 pings/second, with an along track beam angle of 2°. A maximum vessel speed of 4.0 kts was maintained thus any feature at 100 m offset would have at least 3 pings of ensonification, thus meeting the 3 ping NOAA hydrographic standard. The tow body altitude was to be maintained between 80 and 100 meters above the seafloor. Since 2048 pixels were logged across each digital record, the pixel resolution was approximately 25 cm while using the 500m swath setting. The pulse length was 10 cycles, thus a 15 cm across track resolution was resultant. The depression angle of the transducers was set to approximately 45°.

The tow body position was tracked using a Sonardyne ultra short baseline (USBL) system. The USBL transceiver was mounted on a through-hull pole and positioned with an orientation 20° aft of vertical. Since the USBL system accuracy is approximately 2 percent of the water depth, positional accuracies could be expected to range from 2-7 meters based on the range of depths encountered during this survey. To more accurately define the position of the tow body, as computed by the USBL, water depth was measured with a 3.5 kHz Knudsen 320B echo sounder and depth was manually entered into the USBL system. The tow body altitude was measured and then the tow body depth was computed. The preceding information along with the measured phase differences in the USBL were used to obtain an azimuth and range for positioning the tow body.

Two survey lines were run parallel to the as-built route of each cable, offset by 100 meters to the north and south of each cable. This placed the cable in the middle of one channel of the sonar record to provide enough overlap so that the outer portion of one sonar run would cover the distorted nadir area of the adjacent run.

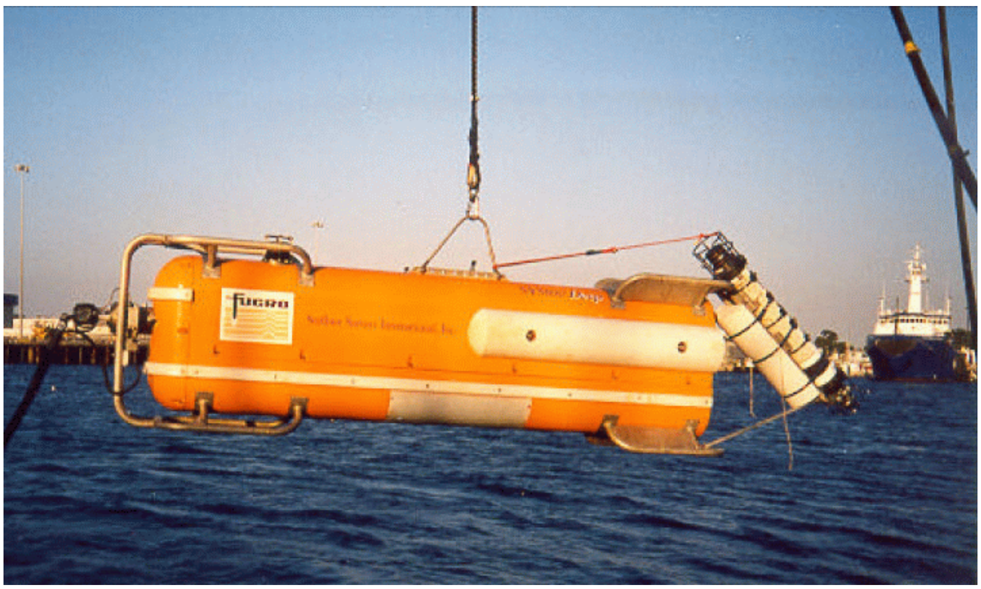


Figure 2. FUGRO SYS100D

3 IMAGE DATA PROCESSING AND TEXTURE ANALYSIS

3.1 IMAGE DATA PROCESSING

Image mosaics were processed and created by FUGRO using their own proprietary software. The exported mosaics were not at full resolution, however full resolution imagery can be available at the FUGRO office in Seattle. All images were reprojected to UTM projection (Zone 10), using Erdas Imagine. Individual images collected at the 250m range scale were then mosaiced using Erdas Imagine and resampled to 2m pixel resolution prior to being exported as tiff format with an associated world file for geospatial positioning. The mosaiced tiff image was converted to raw binary format in Adobe Photoshop to remove all header information, thereby leaving a simple binary file merely containing grey-scale pixel intensities.

3.2 TEXTURE ANALYSIS

Several studies (Skohr 1991; Blondel 1996) have found the use of grey level alone for assigning classification codes to side scan sonar imagery as being inadequate. Thus a co-occurrence matrix approach was instead used as a preferred alternative for classifying the imagery, since it has been found too more effectively assess the spatial relationship of pixel intensities from remote sensing data (Haralick 1973; Blondel 1996). An image classification routine was performed on the mosaiced 2m image through the use of an automated image analysis routine that uses entropy and homogeneity textural indices (Cochrane 2002). Other studies (Blondel 1996) have successfully used entropy and homogeneity indices to effectively classify side scan sonar data, thus these indices were chosen for texturally classifying the imagery in this study.

Binary code for the texture analysis procedure was obtained from the USGS (Cochrane 2002) and compiled in Linux Mandrake 9.1. The initial procedure involved running the binary program called TexScal. This first step calculated the range of values for entropy and homogeneity and assigned correction values that rescaled floating point values to 8-bit numbers within a range of 0-255 to be on a similar scale as the data from the raw side scan imagery. Next, the program TexGen was executed to create the entropy and homogeneity textural index images. TexGen accepts both the range and scaling factors for the homogeneity and entropy indexes that were calculated during the TexScal procedure. Textural signatures were then selected for training the classification program by using Erdas Imagine to visually locate individual signatures for each of the sediment types. Map coordinates for pixels from a 10x10 bounding box for each of the training signatures were entered into the program TexSig. TexSig takes the map coordinates and locates the grey scale values at each pixel location from the entropy, homogeneity, and side scan images, to create the final classification signatures for input into TexClass. TexClass was then executed which used the signatures files created in TexSig to create a thematic grey scale image from the three continuous grey scale images (homogeneity index, entropy index, and the raw side scan image) which represented the classified image. Figure 3 graphically illustrates the indice values for the training areas. This procedure was run four separate times to create individual classification images for each sediment type (sand_silt_clay, fine_mixed_sediment, coarse_mixed_sediment, and rock_boulder) that was visually observed in the side scan imagery. Adobe Photoshop was used to visually remove data that was determined to misclassified or to to remove null data for each class. The mosaic feature in Erdas Imagine was then used to merge the four edited thematic images into one final image.

4 SURVEY EFFORT RESULTS

An area of approximately 59.6 km^2 was surveyed over the course of 2.5 days (Figure 3). A total of six survey lines were collected. The first two lines were collected using a 500 m swath width setting (250 meter range scale). Four more lines were subsequently run using a 200 m swath width (100 meter range scale) to provide higher resolution imagery.

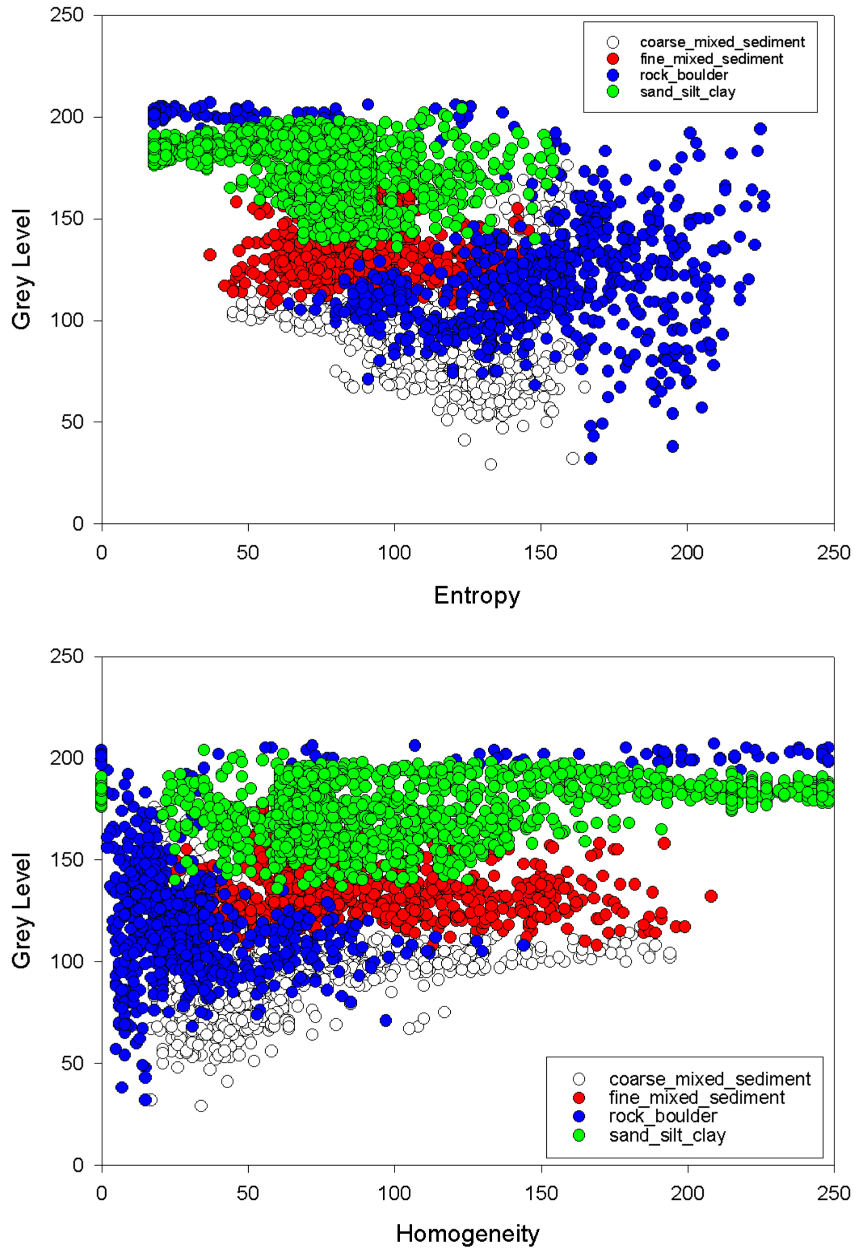


Figure 3. Textural indice values calculated for training areas. The top graph shows entropy verses grey level. Entropy values are high for rough areas. The bottom graph shows homogeneity verses grey level. High homogeneity values result from organized and poorly contrasted featres. The varying colors correspond to the four seafloor classes.

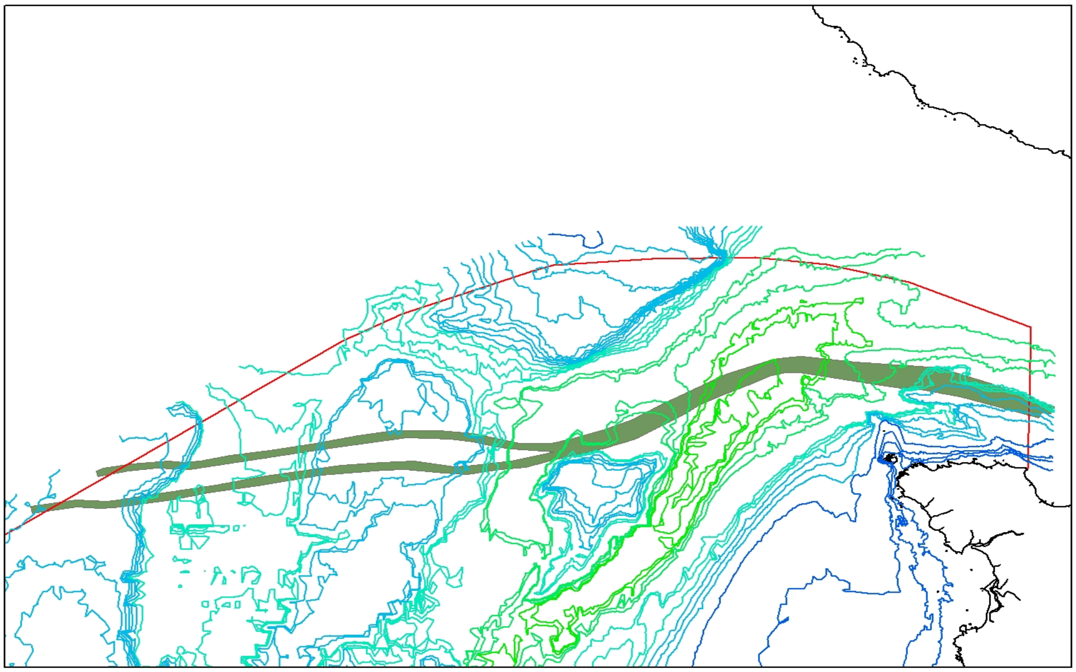


Figure 4. Side scan sonar coverage from the post-lay inspection survey.

4.1 CABLE SCOUR OBSERVATION

The mosaiced image was reviewed for cable, trawl, and grapnel scours. Geologic features were easily distinguishable; however, scours other than from the cable installation were not readily visible from the sonagrams. With the chosen sonar settings, the SYS100D proved to be an appropriate system for sediment mapping and mid-water bathymetry but had limited use for collecting shallow water bathymetry or creating imagery for scour mapping. An transducer with a shallower depression angle being towed closer to the seafloor would provide for a more effective method of mapping scours. However, the cable installation scour was readily visible in the imagery. The survey lines occasionally crossed directly over the cable scour making it impossible to observe the scour. These areas were classified as not visible so there is a slight bias towards non-visible scours when in fact the cable may have been visible. Cable scour on the north cable was visible 47% of the length through the Sanctuary while it was visible 39% of the length of the east cable (Figure 4).

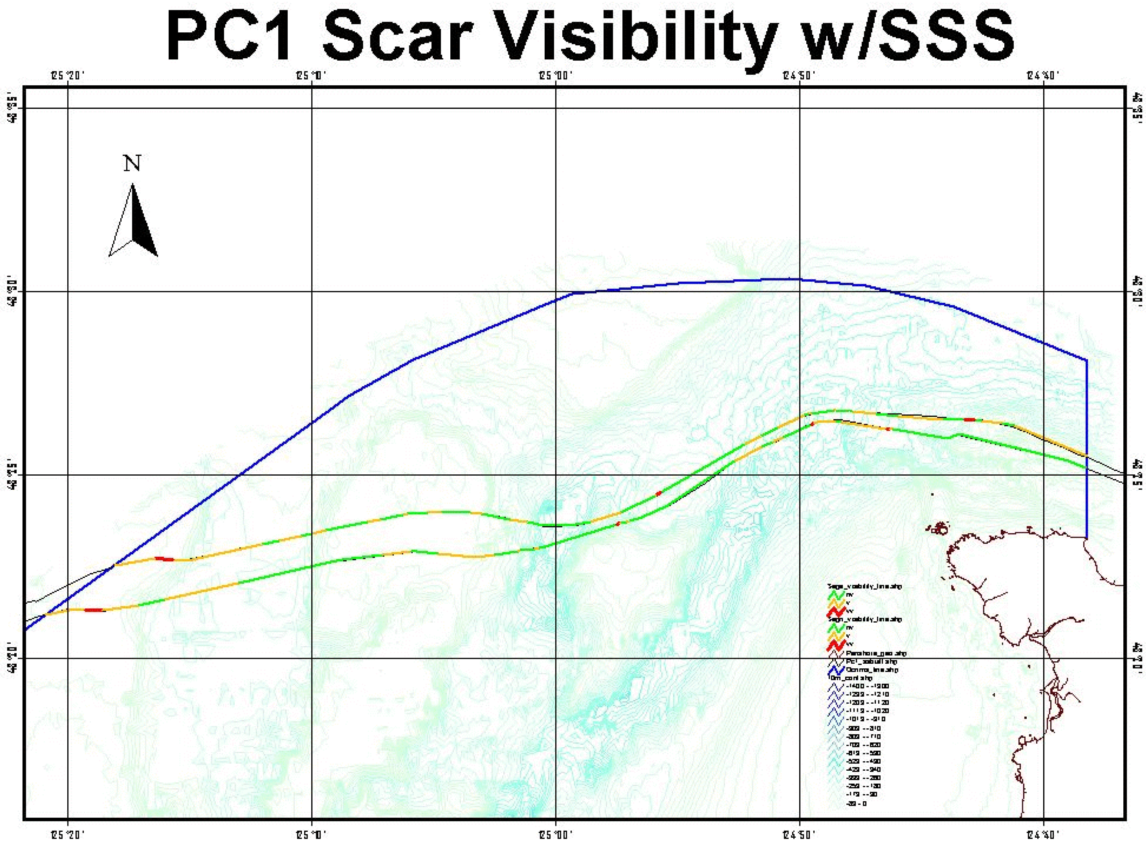


Figure 5. Areas of trench scarring visible in side the scan sonar imagery.

The easily visible sections appear to correspond to the jetted areas of the route. It should be noted that the visibility of the scour cannot be construed as exposed or buried cable. The only reliable method for making that statement is through video inspection.

Two areas along the route showed definite signs of a change in sedimentation clearly due to the existence of the cable.

The geographic positions of the two sites are:

Cable	Longitude	Latitude
Segment N	124º57.47 W	48º23.97 N
Segment N	125º15.00 W	48º22.69 N

Speculation is that the cable is probably exposed and is possibly suspended in these areas. A cable suspension could change the current regime in the immediate vicinity where turbulence in the wake of the cable create an eddy where finer sediments are kept in suspension and may be deposited further down current. This would expose harder sediment that would be reflected as increased backscatter intensity is observed. However a similar effect on the backscatter intensity would be observed in an increased deposition by creating a berm which would increase the slope of seafloor towards the tow body track thus increasing the backscatter intensity received.

It should also be noted that in two fairly lengthy areas it appears that the cables actual location was as much as 170 meters off of the reported as built route position list (RPL). Most of the observed cable was where it was reported, within the margin of error for the navigation systems. This discrepancy can be resolved in careful examination of the digital survey records or could be resolved during the ROV cruise.

4.2 BOTTOM CLASSIFICATION

Visual examination of the side scan reflectivity indicated that four texture classes could likely be discerned using the textural index classification method (Table 3). A four class thematic image (Figure 5) was produced from the texture analysis dividing the seafloor into a sand/silt/clay (class 1), fine mixed sediment (class 2), coarse mixed sediment (class 3), and rock/boulder class (class 4).

Table 3. Pixel statistics for each thematic class produced from the textural index classification.

Sediment Type	Class	Gray Scale	Pixels	% Pixels	Area_km^2
Coarse_Mixed_Sediments	3	170	6,662,260	43.195	26.925
Sand_Silt_Clay	1	85	5,893,184	48.883	23.685
Fine_Mixed_Sediments	2	120	1,059,113	7.766	3.937
Rock_Boulder	4	255	28,556	0.002	0.102

The survey area was classified as mostly mixed coarse sediment (43%) and sand/silt/clay (48%). By following the Greene classification (Greene et al. 1999), these areas would be designated as Outer Continental Shelf to Upper Continental Slope mesohabitats (based on depth), covered with mixed sediments, and mud or sand macrohabitats. Significant areas of fine mixed sediment with scattered cobble and boulder were also present throughout the survey area, along with a few areas of rock outcropping. These areas would also be defined as macrohabitats.

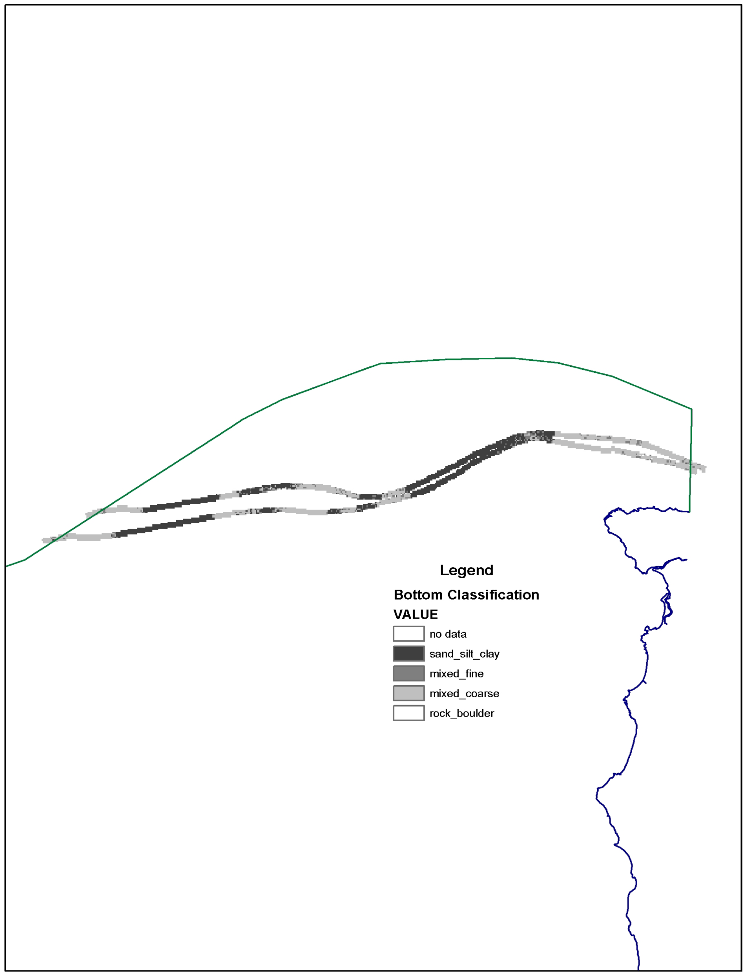


Figure 6. Seafloor classification results from the textural analysis.

5 GROUNDTRUTHING

Groundtruthing information was obtained from grab samples and videography. OCNMS collected grab samples on various occasions during the annual cable monitoring cruises from 2000-2003 (Figure 6). Sediment information was also obtained in the study area from the USGS USSEABED project. Video data was also collected along the entire cable route using a GM ROV and from multiple ROVs and the Delta submersible during the annual OCNMS monitoring cruises. Grain size analysis from the grab samples revealed sediments ranging from silt, sand, and clay, to gravel. Review of the video noted similar observations along with areas of gravel, gravel mixed with cobbles, pebbles and scattered areas of boulders.

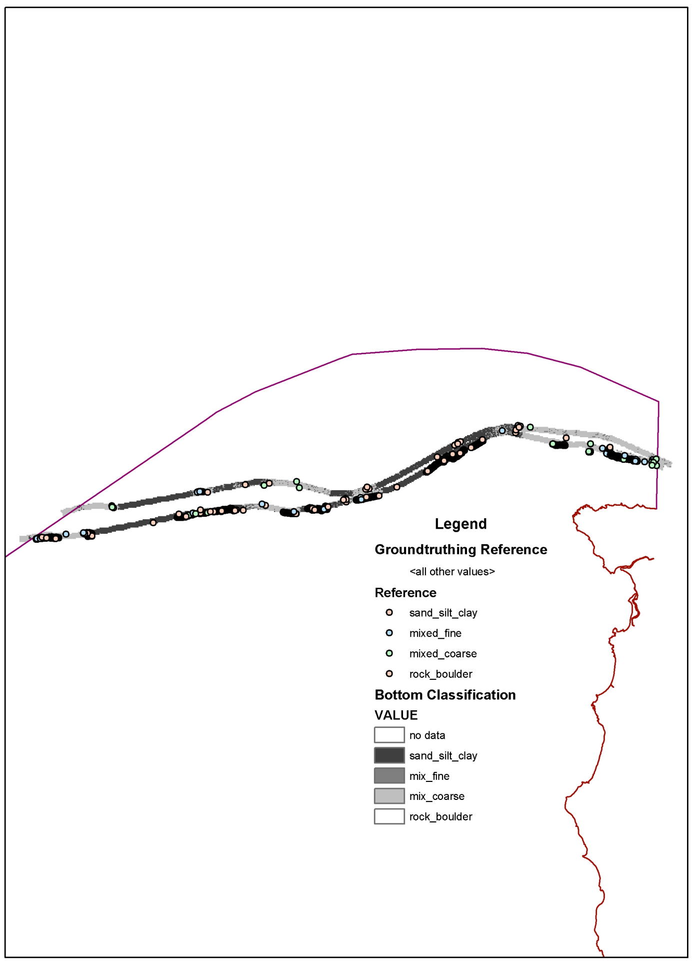
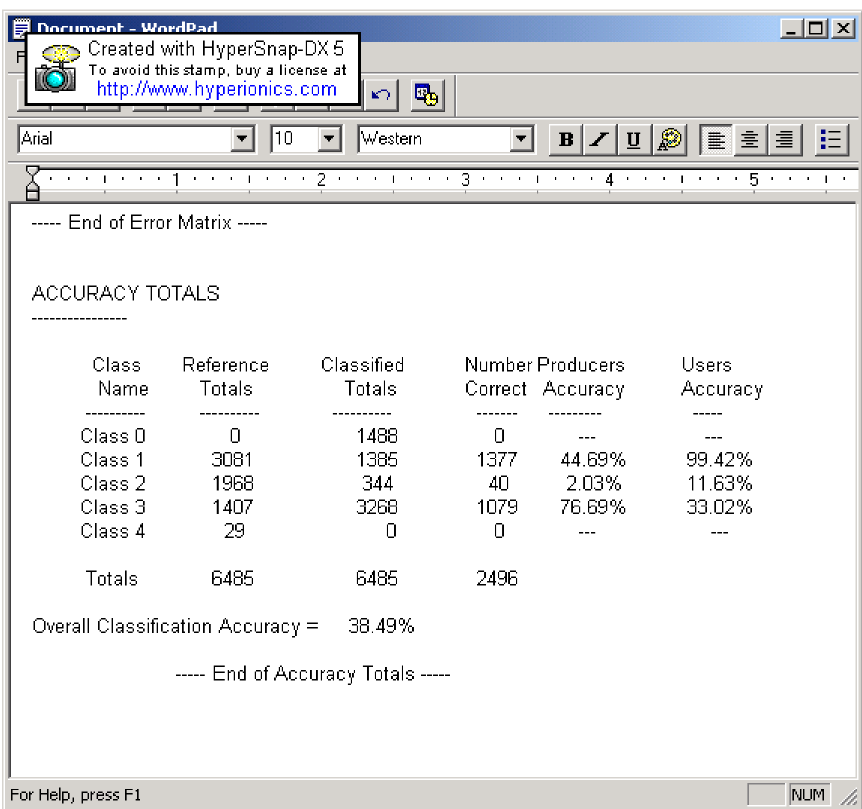


Figure 7. Groundtruthing reference stations obtained from video and grab samples.

6 ACCURACY ASSESSMENT

A reference text file was created from the grab samples and the video efforts. From the grain size results, the reference point was reclassified as being Class 1 if the sample contained greater than 70 percent of a combination of sand, mud, or clay. The reference point was classified as Class 2 if the sample contained between 30 and 70 percent gravel, and Class 3 if the sample contained greater than 70 percent gravel. The reference point was classified as Class 4 if the USSEABED database determined the area to be rock. Video observations were made noting transitions between various bottom types and were linked to the navigation point data which was logged from the ROV or submersible thereby allowing an XYz' file to be created where z' was the observed bottom type.

An accuracy assessment cell array was then created to compare the classified image with the reference point data (Leica Geosystems & Mapping 2003) . The cell array was simply a list of class values for the pixels in the classified image file and the class values for the corresponding reference pixels. An error matrix report was then created in Erdas Imagine which compared the reference points to the classified point in a *c x c* matrix, where *c* was the number of classes. The final report presents statistics of the percentage of accuracy based on the error matrix (Figure 7).



----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Class 0	0	1488	0	---	---
Class 1	3081	1385	1377	44.69%	99.42%
Class 2	1968	344	40	2.03%	11.63%
Class 3	1407	3268	1079	76.69%	33.02%
Class 4	29	0	0	---	---
Totals	6485	6485	2496		

Overall Classification Accuracy = 38.49%

----- End of Accuracy Totals -----

Figure 8. Image classification accuracy assessment error matrix results.

Of the 6,485 reference points 1,488 existed in areas that were unclassified in the image. Class 1 (sand_silt_clay) was classified with 99.42% certainty. Class 4 was not classified at all since no grab samples were taken from rocky areas and the video evidently did not cross the few areas of rock or boulder that existed in the imagery. The poor classification success of Class 2 and Class 3 (11.63 and 33.02 percent respectively) was likely the result of the fine mixed sediment and the coarse mixed sediment not being readily distinguishable from each other in the texture analysis. A success of classification would likely result if these two classes were combined into one mixed sediment class.

6 LITERATURE CITED

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7 APPENDIX

7.1. SCHEDULE AND COMMENTS FROM R. FLETCHER

The vessel Moana Wave, under contract to SSI, was delayed from the original schedule because of weather. The Moana Wave departed the City Pier in Port Angeles at 0900 on May 16, 2001. The vessel was on station on the north segment at the east end of the Sanctuary and deployed the SYS100D at 1420. The first run 100 m north of segment N was completed at 2220. At the completion of the first run it was found that no trawl scours were found. GC conducted the second run at the same scale and settings to map the southern cable. The second run was run from West to East and to the north of the segment E cable. The idea of changing settings will be open for discussion at the completion of the second cable run. The second line was completed at 0650 on the 17th. No trawl scours were observed during acquisition.

After the second 500 m swath line was run the following acquisition changes were made at my request. The swath width was reduced to 200 meters. Pulse repetition rate remained at 2 pings per second and the pulse width was reduced to 5 cycles and the altitude maintained at 60 –80 meters. With these settings the theoretical across track resolution of the sonar image is approximately 7.5 cm and the pixel resolution is 10 cm. The second run on segment N began at approximately 0730 and ended at 1415. As a result of the GC representative observing more features, cable, and other scours a third line at the 200 meter swath width will be run on the North cable before commencing work, two additional lines on the east cable using the same settings.

A total of six lines were run:

Line #	Swath Width	Cable Orientation	Direction	Date	SOL (UTC)	EOL (UTC)
1	500	North of Seg. N	West	3/15	2147	0521
2	500	North of Seg. E	East	3/16	0610	1350
3	200	South of Seg. N	West	3/16	1358	2131
4	200	North of Seg. N	East	3/16	2144	0439
5	200	North of Seg. E	West	3/17	0504	1231
6	200	South of Seg. E	East	3/17	1244	2130